LATITUDE-VARIATION, EARTH-MAGNETISM AND SOLAR ACTIVITY.

IN the *Astronomische Nachrichten* (No. 3619) I have published the results of an investigation dealing with the effects of periodic changes in solar activity on the motion of our planet. It is there shown that these changes, as indicated by the frequency of sun-spots, exert a subtle but pregnant influence on the secular variations of the earth's elements; and, moreover, that disturbances precisely similar to those which appear in the observations of the obliquity and of the sun's longitude are distinctly exhibited in the variation of terrestrial latitude.

In the further pursuit of these researches I have been led to conclude that the anomalies existing in the observations of the sun's right-ascensions and declinations are to be attributed exclusively to changes in the position of the earth's axis of rotation with regard to the axis of maximum moment of inertia, and that these changes in their turn are intimately connected with the varying display of forces on the solar surface. In a subsequent article which appeared in NATURE (No. 1584, March 8) I made a suggestion as to the nature of this connection, and advanced the hypothesis that the magnetism of the earth is probably the medium through which the changes of solar energy react upon the motion of the earth's pole.

In view of the results of Joule's experiments regarding magnetic strain in iron rods, it seems reasonable to believe that something similar to the molecular displacement in the rod may take place in a magnetic body like our earth with respect to its magnetic axis. As has long been known, this axis is by no means coincident with the earth's axis of figure, but is inclined to it, according to Gauss, at an angle of about 12°. It is therefore not unnatural to conclude that a molecular strain in the direction of the magnetic axis will occasion an asymmetric change of the earth's figure, and will thereby produce a displacement of the axis of figure relative to the instantaneous axis of rotation. Such a displacement could remain constant only so long as the total magnetic potential of the earth was not subject to alteration, in which case the pole of rotation would describe a circle of constant radius round the pole of figure as centre. But, as already stated, various facts compel us to believe that the magnetic potential of the earth does alter, and, indeed, changes synchronously with the state of solar activity—the most striking instance being the regular increase of auroræ and of magnetic disturbances with the increasing frequency of sun-spots. Now, if we consider auroræ as discharges of the earth's electric force, it follows that the strain in the direction of the magnetic axis should abate after an auroral display, and the pole of figure should therefore approach the pole of instantaneous rotation.

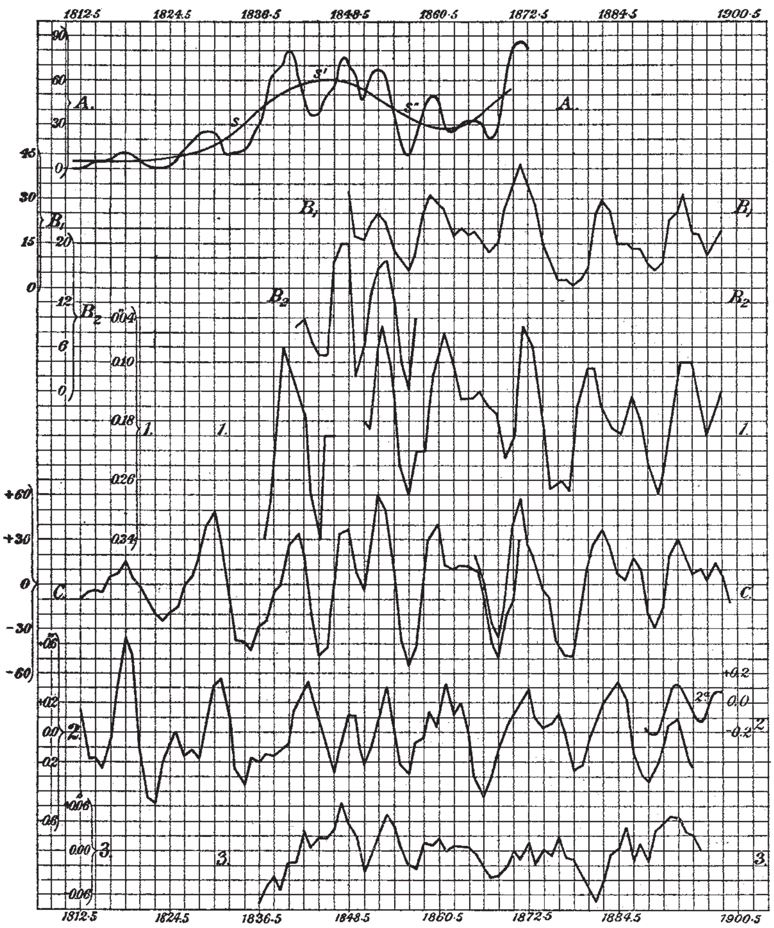

Fig. I.
(From 'Ast. Nach.' 3649)

A, frequency of auroræ (Loomis); B_1, frequency of magnetic disturbances at Greenwich (Ellis); B_2, frequency of magnetic disturbances at Greenwich (Airy); C, frequency of auroræ (Europe south of Arctic Circle) from 1812–1871 (Fritz), and in Scotland from 1865–1899. The "great" period has been eliminated in both curves in order to exhibit more clearly the eleven-years' fluctuations. 1, semi-amplitudes of latitude-variation (Chandler, Nyrén and Albrecht); 2, residuals of obliquity (Fig. C in *A.N.* 3619); 3, Greenwich corrections to the R.A. of stars derived from observations of the sun (Thackeray).

The outcome of this hypothesis would be that changes in the state of solar activity, since they produce a measurable effect on the terrestrial magnetic forces, should also be accompanied by corresponding changes in the motion of the earth's axis. In *A.N.* 3649 I have endeavoured to test this theory by such facts as have up to the present been discovered regarding the complex phenomenon of latitude-variation, and I shall here briefly describe the results there obtained.

In the first place, from the material afforded by the investigations of Loomis and Fritz, and from observations made in Scotland during the past thirty years, I constructed curves exhibiting the frequency of auroral displays from 1812 to 1899. (Fig. 1, curves A and C.) In these the nfluence of the eleven-years solar period is most conspicuous, but there is also exhibited an intimate connection with the "great" cycle of sun-spots. In contrast with the spot-curve, minima of auroræ are found to be of unequal heights. Accordingly, if a second curve *ss's"* be drawn through the aurora-curve A in such a way as to bisect as nearly as possible every wave appearing in it, this new curve will be seen to attain its maxima and minima simultaneously with the "great" spot period. It is therefore beyond dispute, as already proved by Wolf and Fritz, that the existence of this "great" period of solar activity is an established fact, and that it is clearly brought out by the curve of auroræ.

In the next place, curves were formed to show the variations in the frequency of terrestrial magnetic disturbances. For this purpose I took the annual number of days on which such disturbances were observed at Greenwich, as recorded by Mr. Ellis in *Monthly Notices* 60, December 1899. (Fig. 1, curve B_1.)

Mr. Ellis subdivides his records according to the intensity of the disturbance, but only three of his subdivisions were taken into account; those, namely, showing the frequency of moderate, active, and great disturbances respectively. For the satisfactory combination of these different sets, the principle was adopted that the weight assigned to each set should be inversely proportional to the mean frequency—unit weight being given to the "active" disturbances—on the ground that the small frequency of "great" disturbances is probably compensated for by their much more energetic character. In order to extend the record as far back as possible, a similar curve (Fig. 1, B_2) was constructed, based on Airy's statistics from 1841–1857 (*Trans. Roy. Soc.*, vol. cliii.).

These magnetic curves are in perfect harmony with those of the auroræ, and both sets bring out a remarkable and, for our purpose, eminently important fact, namely, that although for the most part they correspond closely with the eleven-years spot period, there nevertheless appear waves which at first sight seem to have nothing to do with the display of solar activity. Most noticeable in this respect are the maxima of 1852 and 1864, of which the former especially seems almost to contradict the existence of a connection between sun-spots and auroræ. A closer examination of the spot-curves, however, reveals the fact that in these two instances there occurred, at exactly the same times, peculiar disturbances or irregularities in the exhibition of spots on the solar surface, so that, after all, the waves exhibited at these points in the magnetic and auroral curves may be supposed to have been caused by solar influence, although they appear for some reason or other on a greatly exaggerated scale. This is decidedly the opinion of Prof. Fritz and of Mr. Ellis, both of whom expressly mention instances of this character, the latest having occurred in 1898 following the spot-maximum of 1894.

The succeeding part of this research may be conveniently divided into two parts. In the first, the earth-magnetic variations are compared and contrasted, in relation to the eleven-years period of sun-spots, with certain phenomena associated more or less directly with latitude-variation; and in the second with similar phenomena relative to the "great" sun-spot and aurora period.

These phenomena are:—

I. With regard to the eleven-years period—

i. The semi-amplitudes of latitude-variation.

ii. The periods of latitude-variation.

iii. The changes in the values of the obliquity as observed at Greenwich from 1812–1896.

iv. Mr. Thackeray's corrections to the right-ascensions of stars derived from observations of the sun during the years 1836–1895.

II. With regard to the "great" period—

v. Dr. Chandler's long period inequality in the latitude-variation.

vi. The observed residuals of the obliquity from 1753–1896 as compared with Leverrier's tabular values.

vii. The Greenwich corrections to the sun's right-ascensions relative to a fundamental system of fixed stars, according to Prof. Newcomb.

The data requisite for the formation of the curve of semiamplitudes (Fig. 1, curve 1) was taken from Dr. Chandler's paper in *A.J.* No. 277, and from the publications of Dr. Nyrén (*A.N.* 3166), Mr. Wanach (*A.N.* 3112) and Prof. Albrecht ("Berichte über den Stand der Erforschung der Breitenvariation"). It has to be borne in mind, as pointed out in my previous papers, that the latitude phenomenon lags behind the comparison magnetic curves by about 1·5 years. Such a lag appears indeed to be a characteristic feature common to most terrestrial phenomena which have hitherto been found to be influenced by solar activity. In this connection I must refer to the highly important and interesting discovery made by Sir Norman Lockyer some years ago, that the curve representing the frequency of the "unknown" lines widened in sun-spot spectra during a cycle of solar activity follows the spot-curve by exactly the same interval, viz. 1·5 years. I have received a communication from Sir Norman, stating that this curve of "unknown" lines goes excellently with my curve 1 of Fig. 1, the maxima and minima of the spectroscopic curves showing a perfect synchronism with those of the curve of latitude-variation. I take this opportunity of expressing my indebtedness to Sir Norman Lockyer for drawing my attention to this most significant and singular fact.

The lag in the case of curve 1 has been allowed for by shifting this curve one and a half years in the backward direction. When it has thus been made to coincide with the comparison curves, their correspondence becomes most striking—a remarkable feature being the exactness with which certain secondary maxima in 1865, 1887 and 1898 are represented in each case.

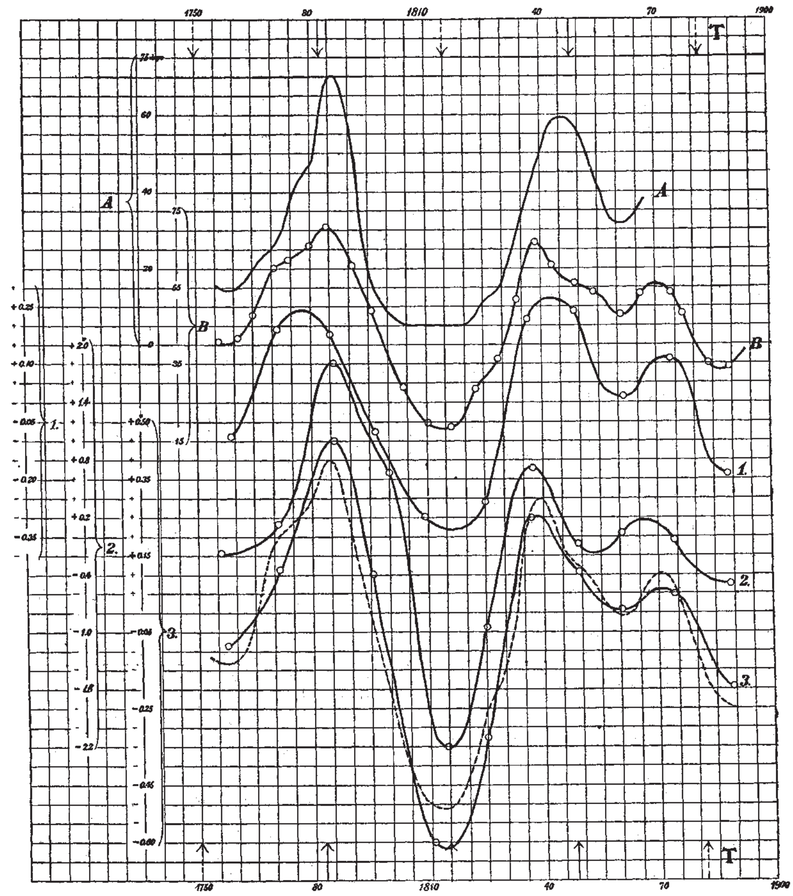

Fig. II.
(*From "Ast. Nach."* 3649.)

T, turning points of Dr. Chandler's long period inequality of latitude-variation; A, great period of auroræ (Loomis). (The ordinates represent eleven-years' means of Loomis' annual aurora-numbers.) B, great period of sun-spots (Wolf); 1, twelve-years' means of residuals of obliquity (Greenwich observations) after elimination of purely secular change; 2, twelve-years' means of corrections to the sun's R. A. relative to a system of fixed stars (Greenwich observations) after elimination of purely secular change; 3, combined curve of obliquity and sun's R.A., the dotted curve representing Wolf's great period of sun-spots on a somewhat different scale.

Indeed, so accurately are the motions of the amplitude-curve shadowed in those of the magnetic variations, that to any unprejudiced astronomer this fact in itself must indicate with sufficient force the existence of a *vera causa*.

The periods of latitude-variation afford a new and almost as certain proof of the existence of an intimate connection between the polar motion and earth-magnetic phenomena.

Dr. Chandler has already shown that a small amplitude corresponds to a great period and *vice versâ* (*A.J.* 277, p. 98). How well this influence is borne out may be seen from the following analysis of the average values of r according to the lengths of the period:—

Period in days.		Observed r.		Computed r.
		"		"
Under 390	...	0·20	...	0·20
390–420	...	0·18	...	0·19
420–450	...	0·15	...	0·13
Over 450	...	0·10	..	0·08

This statement in itself constitutes a proof of my assertion, and renders it unnecessary for me to add anything further on this point. Any one who cares to plot down the values for the periods given by Dr. Chandler must arrive at the conclusion that the comparison of the curve so obtained, with the magnetic and auroral curves, gives indeed a convincing argument in favour of the earth-magnetic hypothesis.

I have next to consider the changes in the values of the obliquity as observed at Greenwich due to the eleven-years period of solar activity.

In my paper, *A.N.* 3619, I have discussed fully the reduction of these values to a uniform and homogeneous system, as well as the elimination from them of the secular variation and the influence of the "great" sun-spot and aurora period. The resulting curve (Fig. 1, curve 2) exhibits the utmost conformity with those of the earth-magnetic and latitude phenomena.

This fact is of the highest significance, inasmuch as it affords added testimony to the accuracy of the data on which my research is founded. The curves communicated show that at times, when the amplitude of latitude-variation reaches maximum values (1½ years after minimum displays of magnetic disturbance), the Greenwich obliquity attains small values; while at times, when the amplitude is at a minimum (1½ years after maximum displays of magnetic disturbance), the obliquity appears to be excessively great. This leads at once to the conclusion that whenever the amplitude is great, the minimum latitude for the Greenwich meridian must occur near the time of the winter solstice, and that when the amplitude is small just the reverse ought to take place. Now Dr. Chandler's statistics in *A.J.* 277 afford ample means of testing this conclusion. In point of fact they show that at times of maximum amplitude the epochs of minimum latitude for the Greenwich meridian have always occurred on some date between the beginning of November and the end of February, while at times of amplitude-minima these epochs, with the exception of the first in 1840, are comprised within the interval from May to August. The mean date in the former case is January 10, and in the latter July 16; and the mean deviation of a single epoch from these two dates is not more than about ± 40 days.

I consider that, in spite of the great uncertainty which naturally attaches to researches of so delicate a character, the evidence afforded by these results is to be taken as a proof that the residuals in the obliquity, far from being accidental, are really caused by latitude-variation. Thus, owing to the great extension of the series of Greenwich solar observations, these residuals form an excellent test of my assertion that the motion of the pole depends on the intensity of the earth-magnetic forces.

As regards the corrections to the right-ascensions of the stars derived from Greenwich observations of the sun, I need only state that after subtracting the secular variation found by Mr. Thackeray (*M.N.* June 1896), the resulting values give curve 3 of Fig. 1, which, in spite of somewhat large accidental discrepancies, is in general agreement with all the others, especially with that of the obliquity.

Having thus shown that my contention with regard to a connection between the eleven-years period of auroral displays and magnetic disturbances and the motion of the earth's pole of rotation appears to be borne out by all the facts which constitute the sum of our present knowledge of the peculiar phenomena relating to latitude-variation, I next consider the "great" period of auroræ, which, as already stated, is synchronous with the great period of solar activity.

For this purpose I exhibit in Fig. 2 curves showing the great aurora-period according to Loomis' annual numbers, and the great spot-period in Wolf's relative numbers.

The interval comprised by this great period is according to Wolf equal to six small cycles, *i.e.* sixty-six years. Now this is exactly the period of Dr. Chandler's long inequality of latitude-variation. The smallest amplitudes and greatest periods of latitude-variation, according to Chandler's formula, fell in 1782 and 1848, almost exactly at the times of greatest auroral displays; whereas the greatest amplitudes and smallest periods occurred in 1815 and 1881, *i.e.* just at the times when the display of auroræ reached a minimum.

But in addition to this there are other facts which point to an influence on the earth's motion exercised by some force varying with the great period of solar activity. In my previous papers I have discussed at some length the evidence afforded by the curves representing the observed residuals of the obliquity, and Prof. Newcomb's corrections to the right-ascension of the sun relative to a fundamental system of fixed stars. I therefore need not here dwell upon their importance as strongly supporting my hypothesis.

A reference to curves 1, 2 and 3 of Fig. 2 will show how exquisitely parallel are their courses, and how complete is their agreement, not only with the changes in the displays of auroræ and solar activity, but also with Dr. Chandler's long period inequality. It seems utterly inconceivable that a correspondence so consistent can be attributed merely to accident.

It remains to state briefly one or two very important and interesting deductions made from the results of the last ten years' researches into the phenomena of latitude-variation.

The frequency of auroræ and magnetic disturbances, as is well known, shows, in addition to the variations associated with changes of solar activity, other fluctuations depending on the season of the year—a fact which has been closely investigated and corroborated by Mr. Ellis. It appears that the magnetic disturbances recorded at Greenwich reveal decided maxima at the equinoxes and minima at the solstices, thus betraying, like the auroræ, a half-yearly period.

Now the foregoing results point to the conclusion that the distance of the pole of instantaneous rotation from the pole of figure depends on the display of earth-magnetic forces. Hence in the course of a year this distance must become twice comparatively short and twice comparatively long; *i.e.* instead of being circular, the path described by the pole of rotation round the pole of figure must be elliptical—the mean pole being situated at the centre of the ellipse. If the period of polar motion were exactly one year, the position of the axes of this ellipse referred to a fixed meridian would remain unaltered. But from Dr. Chandler's investigations we know the period of latitude-variation to be on the average 428 days. Hence the effect of seasonal change in the earth-magnetic forces must consist in continuously rotating the axes of the polar ellipse in a direction opposite to that of the motion of the pole. These conclusions are well corroborated by the observed facts, and are clearly revealed in the plate appended to Prof. Albrecht's latest "Bericht." The comparatively great eccentricity of the ellipses admits of a tolerably accurate determination of the angles between their major axes and the Greenwich meridian. If the magnitudes of these angles be computed (Table vi. of my paper, *A.N.* 3649), it will be found that they exhibit quite unmistakably the progressive change of position of the ellipse with regard to the meridian, the average angular distance between two successive positions of the major axes being about 33°.

But a closer examination of these figures shows that they indicate fluctuations in this average amount which stand in a remarkable connection with the varying display of magnetic disturbances.

The motion of the ellipse appears to have been largely progressive in 1892, 1894 and 1898; while it has been very slight, and at times even retrograde, in 1890, 1893 and 1896. In the first-mentioned years the ellipses are also more irregular and distorted than in the others, indicating a more vehement and spontaneous character of the forces acting on the motion of the pole. Now, according to Mr. Ellis, these years were the *only ones* in which magnetic disturbances of the character "great" occurred at Greenwich, while in the last-named years his statistics show that there prevailed a decided magnetic calm. While leaving the final confirmation of this interesting fact to future observations, it does not seem too much to say that in the face of existing evidence it is difficult to retain the idea that a coincidence so peculiar can possibly be ascribed to mere accident.

The results of my researches may be thus shortly summarised:—

i. The changes in the motion of the pole of rotation round the pole of figure are in an intimate connection with the variations of the earth-magnetic forces.

ii. Inasmuch as the latter phenomena are in a close relation with the state of solar activity, the motion of the pole is also indirectly dependent on the dynamical changes taking place at the sun's surface.

iii. The distance between the instantaneous and mean poles decreases with increasing intensity of earth-magnetic disturbance.

iv. The length of the period of latitude-variation increases with increasing intensity of earth-magnetic disturbance.

v. In strict analogy with the phenomena of auroræ and of magnetic disturbance, the influence of the eleven-years period of sun-spots, as well as of the "great" period, is clearly exhibited in the phenomenon of latitude-variation; and the same deviations from the solar curve as are manifested by the auroræ are also evident in the motion of the pole.

vi. The half-yearly period of the earth-magnetic phenomena influences the motion of the pole of rotation in such a way that its path, instead of being circular, assumes the form of an ellipse, having the mean pole at its centre.

vii. The half-yearly period also explains the conspicuous fact of a rotation of the axes of the ellipse in a direction opposite to that of the motion of the pole. J. HALM.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

PROF. J. G. MACGREGOR, of Dalhousie University, Halifax, Nova Scotia, has been appointed professor of physics in University College, Liverpool, in succession to Prof. Lodge.

THE Calendar of the Glasgow and West of Scotland Technical College, for the session 1900–1901, has been received. Among the contents of the volume we are glad to notice schemes of courses of study, extending over three years, for students who intend to take up some branch of applied science or engineering as a profession. Students are permitted to attend single classes, but they are encouraged to follow one of the regular courses in the several departments of study. This is the only way to derive any real advantage from a Technical College, desultory attendance at classes without any definite object being of little value.

AT a special meeting of the University Court of St. Andrews, held on Saturday last, the proposal of the Marquis of Bute, who offered a sum of 20,000*l.* to be held as a fund for endowing a chair of anatomy in the University, was considered. After deliberation, the Court resolved cordially to accept the proposed gift on the conditions as stipulated by his lordship, and to request the Lord Rector to inform Lord Bute of the Court's decision. The Court further resolved to proceed at once with the creation of a professorship of anatomy at St. Andrews, to be endowed by Lord Bute's gift, the first presentation to the chair being Dr. Musgrove, the present lecturer in anatomy, such presentation to be made as soon as the ordinance creating the chair is approved by her Majesty in Council.

THE mission of science in education was recently considered in some detail by Prof. J. M. Coulter in an address delivered at the University of Michigan, and published in *Science*. The claims set forth in the paper are formulated as follows:—The introduction of science among the subjects used in education has revolutionised the methods of teaching, and all subjects have felt the impulse of a new life; it has developed the scientific spirit, which prompts to investigation, which demands that belief shall rest upon a foundation of adequate demonstration, which recognises that the sphere of influence surrounding facts may be speedily traversed and that everything beyond is as uncertain as if there were no facts; it has introduced a training peculiar to itself, in that it teaches the attitude of self-elimination, an attitude necessary in order to reach ultimate truth, and thus supplements and steadies the other half of life, which is to appreciate. To obtain these results, there must be teachers who can teach, whose background and source of supply is the investigator. Moreover, the results are immensely desirable, inasmuch as they do not interfere with anything that is fine and uplifting in the old education, but simply mean that the possibilities of high attainment and high usefulness are open to a far greater number.

MESSRS. S. Z. DE FERRANTI, the electrical engineers at Hollinwood, near Oldham, have just adopted an educational scheme for their apprentices. Success at evening classes, combined with steady work, are to be the chief recommendations for promotion from one department to another. And the apprentice who obtains the highest position in the South Kensington Examinations in subjects of importance to the theoretical training of an engineer will be awarded a scholarship tenable in the day engineering department of the Manchester Municipal Technical School. His fees will be paid by Messrs. Ferranti, and also the wages he would receive if working in their shops. Mr. F. Brocklehurst takes this generous scheme as the text of a pamphlet upon "Technical Education," issued by the Technical Instruction Committee of Manchester, and he hangs upon it some instructive remarks as to the responsibilities of manufacturers and the nation at large, if England is to maintain her position in the industrial world. Referring to education in Switzerland, he points out that at Winterthur, a small engineering town near Zurich, the technical school is attended by 400 day students who have voluntarily left their employment (sacrificing their wages in so doing) for one or two sessions in order to devote themselves to technical study. The town, the canton and the State combine to assist the realisation of their ambitions by bearing the burden of cost, and in keeping the fees of the technical school low. In the same way the great Polytechnic of Zurich is crowded in its day department with hundreds of young men preparing themselves for the engineering, electrical and chemical industries. Germany provides many similar examples. In the Technical High School of Darmstadt there are to be found 1100 day students, all of them over eighteen years of age, many of them graduates of universities, and the remainder having received a splendid high-class education in secondary schools. These are engaged in the study of electrical, chemical or mechanical science directly bearing upon industrial pursuits. This is only one of many technical high schools in Germany, the culmination of which is seen in the Charlottenberg Technical High School, near Berlin—the finest institution of its kind in the world—with its more than 2000 day students. These young men are being prepared for the highest positions, as technical chemists, mechanical, naval, civil and railway engineers, shipbuilders and architects. There are now in the German Technical High Schools no fewer than 11,000 day students. In connection with the figures given it must be noted that (1) they are exclusive of science students taking university courses; (2) the pupils are without exception youths of over eighteen years of age; and (3) each technical high school insists upon an entrance examination of an exacting character.

The great advance of the United States in engineering is, as Mr. Brocklehurst remarks in his pamphlet referred to above, largely due to the fact that during the last forty years very important engineering schools have been founded. The chief of these is the Massachusetts Institute of Technology at Boston. This is attended by 1171 day students, whose average age at entrance is eighteen years and nine months, and who are either graduates from other colleges or have attended the public high schools for at least four years. The Worcester Engineering Polytechnic has 823 day students. Nearly 1000 are in the Lehigh Engineering College. The Stevens Institute of Technology, New Jersey, has 214; and the Case School of Applied Science in Cleveland, Ohio, 218. Five hundred and ninety-seven day students attend the classes of the Sheffield Scientific School in Connecticut, while the Sibley College of Engineering —part of Cornell University, New York—has 492 day students. There are 242 day students in the Engineering Department of the University of Michigan. A recent report shows that in the Engineering Colleges of the United States the number of day students enrolled is 9659, and that their growth since 1878 is 516 per cent.! Fifty-one per cent. of these students have had a three-year high school course, which would bring them to seventeen years of age. The number of engineering students graduated in 1899 was 1413, and the number of institutions providing an education in this branch of technical instruction (engineering) is 89. This is exclusive of evening work altogether. It is also exclusive of what America is doing in the fields of chemistry and textiles. Little wonder is it that this wealth of educational opportunity is producing its crop of skilled craftsmen trained to compete on more than equal terms with the Briton. The Manchester Technical Institution Committee is doing a service to the nation by placing these facts prominently before the manufacturers of the district.